TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED
IN LONDON
1909

INCORPORATED
1930

ST LOUIS PUBLIC LIBRARY

CONTENTS

	Page
Transport Lighting with Fluorescent Lamps, by H. R. Ruff, B.Sc. *(Eng.)*, M.I.E.E. *(Member)*, J. N. Hull, B.Sc. *(Eng.)*, A.M.I.E.E. *(Fellow)*, and R. V. Mills, Graduate I.E.E. *(Member)*	57
Additions to List of Members	87
Sessional Meeting in London	88
Notice of Annual General Meeting	88
Fellowship	88
Register of Lighting Engineers	88

VOLUME XIV
No. 3 — 1949

32 VICTORIA ST
LONDON, SW1

Annual Subscription to Non-Members - *£2.2.0*
Price per Number to Non-Members - *5s. 0d.*

The I.E.S. Council and Committees
Session 1948-1949

Council

President :—J. M. WALDRAM, B.Sc. (*Fellow*).

Vice-Presidents :—E. C. WALTON, B.Eng., Ph.D., E. W. MURRAY (*Fellow*), J. N. ALDINGTON, B.Sc., Ph.D. (*Fellow*).

Members of Council :—

Elected Members:—

C. J. ALLDERIDGE, A. D. S. ATKINSON, H. S. BARLOW, C. R. BICKNELL, H. BRIGHT, L. J. DAVIES, G. H. GILES, H. F. GILLBE, C. E. GREENSLADE, T. S. JONES, S. D. LAY, E. C. LENNOX, H. A. LINGARD, J. H. NELSON, A. J. P. PASHLER, A. G. PENNY, L. C. RETTIG, J. S. SMYTH, W. T. F. SOUTER, J. F. STANLEY, W. R. STEVENS, P. C. SUGG, S. G. TURNER, F. WALKER.

Ex-Officio Representatives of Centres:—

L. BURDES (*Bath and Bristol*), W. J. P. WATSON (*Birmingham*), J. S. CHILDS (*Cardiff*), S. G. BATT (*Edinburgh*), D. ROSS (*Glasgow*), J. DAVOILE (*Gloucester and Cheltenham*), J. D. GREEN (*Leeds*), F. JAMIESON (*Leicester*), O. C. WAYGOOD (*Liverpool*), H. ATHERTON (*Manchester*), H. L. JAMES (*Newcastle*), E. G. PHILLIPS (*Nottingham*), B. BINGHAM (*Sheffield*).

Hon. Treasurer :—
J. G. HOLMES.

Hon. Secretary :—
H. C. WESTON.

Hon. Editor of Transactions :—W. R. STEVENS.

All Past-Presidents of the Society are *ex-officio* Members of Council.

Committees

GENERAL PURPOSES COMMITTEE: J. M. Waldram (*President*), J. G. Holmes (*Hon Treasurer*), H. C. Weston (*Hon. Secretary*), J. W. T. Walsh (*Past-President*), E. C. Walton, E. W. Murray (*Vice-Presidents*), C. J. Allderidge (*Birmingham Centre*), H. Atherton (*Manchester Centre*).

PAPERS COMMITTEE: A. D. S. Atkinson, C. R. Bicknell, T. S. Jones, A. G. Penny, F. C. Smith, J. S. Smyth, P. C. Sugg.

EDUCATION COMMITTEE: R. O. Ackerley, H. S. Barlow, A. Cunnington, P. Good, C. E. Greenslade, W. J. Jones, S. D. Lay, J. T. MacGregor-Morris, F. C. Smith, W. R. Stevens, J. W. T. Walsh.

I.E.S. CODE COMMITTEE: R. O. Ackerley, C. R. Bicknell, J. H. Nelson, F. C. Smith, J. S. Smyth, W. T. F. Souter, J. F. Stanley, J. W. T. Walsh, H. C. Weston.

DEVELOPMENT COMMITTEE: R. O. Ackerley, A. D. S. Atkinson, T. S. Jones, S. D. Lay, A. G. Penny, L. C. Rettig, S. G. Turner.

AREAS JOINT COMMITTEE: One representative from each Centre.
Council's Representatives: C. R. Bicknell, J. H. Nelson, W. R. Stevens.

(The President, Hon. Secretary and Hon. Treasurer are *ex-officio* members of all committees.)

Secretary :—G. F. COLE, 32, Victoria-street, London, S.W.1.

Transport Lighting with Fluorescent Lamps

By H. R. RUFF, B.Sc. *(Eng.)*, M.I.E.E. *(Member)*, J. N. HULL, B.Sc. *(Eng.)*, A.M.I.E.E. *(Fellow)*, and R. V. MILLS, Graduate I.E.E. *(Member)*

Summary

Lighting of transport vehicles has been stimulated by the introduction of fluorescent lamps, with their higher efficiency, large area and improved colour. After analysing the problem in terms of requirements and limitations, the paper describes the characteristics of lamps and circuits, explaining the choice between direct operation and conversion to a more suitable electrical supply. Following a description of the new types of lighting equipment and lamp control gear, the paper concludes with a detailed account of the application of the systems developed to specific classes of vehicle and the results achieved.

Contents

(1) INTRODUCTION.
(2) PROBLEM ANALYSIS.
  (2.1) Lighting requirements.
  (2.2) Space and weight limitations.
  (2.3) Power supplies.
(3) CHOICE OF SUPPLY.
  (3.1) Lamp characteristics.
    3.1.1. Lamp dimensions.
    3.1.2. Life under traction conditions.
    3.1.3. A.C. and D.C. operation.
  (3.2) Circuit characteristics.
    3.2.1. Effect of frequency.
    3.2.2. Resonant circuits.
    3.2.3. Direct current.
  (3.3) Operation from existing supplies.
    3.3.1. D.C. 12 to 50 volts.
    3.3.2. D.C. 50 to 150 volts.
    3.3.3. D.C. 400 to 600 volts.
    3.3.4. A.C. 110 to 115 volts 250 to 600 cycles.
  (3.4) Conversion equipment.
    3.4.1 Rotary machines.
    3.4.2 Vibrator and commutator inverters.
(4) LIGHTING EQUIPMENT.
  (4.1) Lamps and lanterns.
  (4.2) Control gear.
(5) APPLICATIONS.
  (5.1) Steam trains.
  (5.2) Electric trains.
  (5.3) Tramcars.
  (5.4) Trolleybuses.
  (5.5) Buses and coaches.
  (5.6) Aircraft.
(6) CONCLUSIONS.

(1) Introduction

The paper is primarily concerned with the fluorescent lighting of transport vehicles in Great Britain. The lighting of aircraft presents many similar problems, so that a section has been included to cover this application, but ships have been excluded as involving quite different problems and possibilities.

Vehicle lighting to our present standards represents a considerable achievement, much of which is due to the painstaking efforts of the group of specialist engineers whose task it has been to ensure that the travelling public has been provided with light reliably. These specialists have a fund of experience of oil, gas, and electric lighting, from which designers of fluorescent lighting equipment have been pleased to draw.

The task has always been largely one of making a little spread a long way. Limitations of space or weight have made it possible to provide only just

The authors are with the Research Laboratory of the British Thomson-Houston Co., Ltd., Rugby. The MS. of this paper was first received on October 27, 1948. The paper was presented at a meeting of the Society on January 11, 1949.

enough power for lighting, particularly when such power must be available for emergency conditions. With fluorescent lighting this is still a major problem, and a section of this paper is devoted to the choice of supply.

It is interesting to record that some time before the fluorescent lamp was an established light source the authors were investigating its application to transport vehicles as part of the appraisal of its value as a general lighting tool. When the work had to be shelved in 1939 we had already confirmed that such lighting was practicable. When the task was resumed in 1945, high quality general lighting using fluorescent lamps was already so well accepted that the introduction of the fluorescent lamp inside vehicles seemed almost essential to give the necessary atmosphere of modern well-being and to break away from the artificial effect of small light sources in an unevenly lit interior.

Much of the national effort on transport lighting was summarised for the recent C.I.E. Meeting (1). The completion of this paper was held back to obtain from the National Report and the international discussion at the Conference, data from the experience of others to supplement and extend the authors' appraisal of the application of fluorescent lighting of transport vehicles.

(2) Problem Analysis

(2.1) Lighting Requirements

A concise statement of the purpose of the lighting installations in transport vehicles is not easy because of the diversity of types of vehicle and the different service conditions which they satisfy. For instance, while some tramcars may be only utilitarian means of transport, which must be illuminated inside for the safety of occupants, others are luxury vehicles and attractions in themselves at holiday resorts; a much higher standard of lighting is then required.

Railway coaches need lighting to enable passengers to read at night and in tunnels, but must often be convertible to give a subdued atmosphere appropriate to sleeping. Since, however, many people wish to read, illumination to permit comfortable reading can be set down as a definite requirement.

It is necessary, of course, to provide sufficient light for safe movement, and this is mentioned specifically because the motion of the vehicle adds to the hazards when passengers are alighting or moving about. As it is usually easier to satisfy this criterion, however, it has been placed second to the reading requirement.

A cheerful atmosphere helps to lessen the tedium of long journeys, and in railway carriages, for instance, much development has taken place over many years to improve the comfort of passengers. With all the amenities of modern vehicles, such as dining and buffet cars, hairdressing and sleeping accommodation, conditions during travel may approach those of a modern hotel. Clearly, lighting can make a big contribution to this desirable end.

(2.2) Space and Weight Limitations

Vehicles require power to move them; the larger the load, the greater is the power, and, therefore, the cost of the journey. For economy, most vehicles are designed to be just large enough to accommodate a given number of passengers, and unnecessary weight and space are rigorously excluded in the design. These factors become increasingly important as trains, tramcars, trolleybuses, buses, and coaches are considered, with aircraft as an extreme example.

While the lower brightness of fluorescent lamps as compared with incandescent lamps reduces the need for diffusion and enables uniform illumination to be obtained efficiently, the higher quality lighting entails additional weight, the need for control gear, and, sometimes, power conversion equipment. Be-

cause of the increased lamp size, larger lighting units have usually to be accommodated, although the low lamp brightness often mitigates this disadvantage by allowing simpler types of optical systems.

Consider a corridor coach of a main-line train. Its division into a number of compartments enables a similar lighting layout to be adopted for each. Passengers sit facing one another, so that the desirable direction of lighting for one half will often conflict with that for the other. For reading, light from above and slightly behind is required, and it will readily be realised that lighting units to provide this light can be placed only within a small area below the rack. Placing above the rack would, of course, result in obstruction by luggage. It is from just this area that the passengers opposite are susceptible to glare owing to the nearness of the light source to their normal line of sight. Since the vehicle has been designed to utilise the space to the utmost, the luggage rack, for instance, cannot simply be moved to enable lighting units to be raised. Moreover, the space above the back of the seat is often almost filled with advertisements. Although weight and space limitations may appear less onerous in saloon coaches, the difficulties encountered in practice are similar.

Buses provide an extreme example of space limitations because the width of the coachwork is restricted by regulations and the height by bridges. Designers have been very skilful in allowing just sufficient space for people to get to their seats or to stand, as the case may be, but there is almost no spare space to accommodate lighting equipment. In some types lighting fittings have had to be placed in the window frame, just above eye level and the bright sources may then be quite uncomfortable. There is often, however, an unused portion of space at the cornice, although even this space is broken up by fillets adding strength to the coachwork. One might not think that reading would be a serious pastime in city buses, but in fact many passengers are sufficiently interested in, for instance, the sports results, to be unable to wait for more peaceful surroundings: a book also helps to pass the time while waiting at a terminus.

Long-distance road passenger vehicles are not so numerous here as in other countries, but they are quickly becoming more popular. The longer journeys require a more comfortable and adaptable installation. Weight, too, is an increasingly important factor as gear of all kinds is carried in the vehicles, reducing their "payload." Fluorescent lighting must justify the inevitably increased weight as compared with a filament lamp installation.

Weight is the paramount factor for aircraft lighting equipment and much ingenuity is required to get the most out of small lighting components. The efficiency and characteristics of fluorescent lamps make them very suitable for general lighting of an open cabin, but for reading more local illumination is often necessary especially when the length of the flight is sufficient to encourage some passengers to sleep. The main lighting is then reduced and narrow beam individually-controlled reading lamps either in chair-heads or in the ceiling are essential for the wakeful few. Filament lamps with small specular reflectors may well perform this function.

(2.3) Power Supplies

Fluorescent lamps require control gear to stabilise them and with 50-cycle A.C. supply mains the function of chokes, capacitors and starter switches is now well known. When considering the lighting of vehicles there is at the same time greater difficulty and greater freedom. The difficulty lies in the fact that there is rarely available an effective supply really suitable for operating such lamps; the freedom, lies in the fact that if conversion is necessary, it is

possible to choose a supply system that may be more suitable than the standardised 50-cycle mains.

From the point of view of power supply, vehicles can be considered in two main groups, the first where the power required for the lighting is generated by equipment carried on the vehicle, and the second where power is picked up from the track or overhead lines. In some cases, although the motive power is derived from the track, power for lighting is generated on the vehicle.

One main problem of the first group is the limited power supply. It is usually obtained from axle- or engine-driven generators which charge batteries; these are necessary to provide lighting power when the vehicle is stationary and may have to maintain continuity of supply under emergency conditions such as temporary failure of generation. The batteries help to stabilise the voltage of such supplies but variations are still large unless additional regulating equipment is employed; their use means that the basic supply is low voltage D.C.

With the second group there is usually ample power, generally medium voltage D.C. with large variations due to fluctuations in the traction load and the length of feeders. Further complications are introduced by sectional gaps and by points and crossovers; these cause voltage surges or interruptions, the

Table 1.

Typical Electric Supplies Available For Lighting

Vehicle	Mean Supply Voltage	Variation in Voltage	Approx. Power Available (watts)
Steam Trains... ...	22 D.C.	21–23	1,000 (Per Coach)
	24 D.C.	18–32	1,000 (,, ,,)
Electric Trains ...	50 D.C.	49–51	2,000 (2 Coaches)
	70 D.C.	67–73	4,000 (6 ,,)
	550 D.C.	440–650	3,000 (2 ,,)
	600 D.C.	450–700	3,000 (2 ,,)
	1,500 D.C.	—	—
Tramcars	525 D.C.	450–550	2,000
	550 D.C.	450–650	—
Trolleybuses	35 D.C.	30–39	1,000
	30 D.C.	25–31	500
	500 D.C.		
Buses and Coaches	12 D.C.	9–16	—
	24 D.C.	18–32	720
Aircraft	24 D.C.	23–29	1,000
	30 D.C.	28–35	1,000
	120 D.C.	118–122	2,000
	110–250 Cycles	109–111	1,000
	110–400 Cycles 3 phase	—	4,000
	115–1,600 Cycles	—	375

time and frequency of which are variable being dependent upon the speed of the vehicle as well as the gap distance.

Sometimes larger electric supplies are available for some other main purpose—for instance for cooking or controls in aircraft—which can be utilised for lighting, and for convenience a summary of the more common supplies that may be encountered are collected in Table 1.

(3) Choice of Supply

(3.1) Lamp Characteristics

To give an overall picture of the ways in which fluorescent lamps can be applied to transport lighting, it is helpful to consider certain main lamp characteristics.

(3.1.1) *Lamp Dimensions*

The development of fluorescent lamps has been described in a number of papers.(2). The lamp is essentially a positive column low-pressure discharge lamp, as far as its operation is concerned, and the discharge path is cylindrical in shape. The choice of a particular shape of tubular bulb is easy to understand if one realises the following approximate characteristics:—

(a) The end or electrode losses are a constant waste of power, independent of the length of the lamp. They are mainly dependent upon the type of cathode used. The power lost is approximately the product of the tube current multiplied by 12 volts for hot activated cathodes, 100 volts for activated cold cathodes and 200 volts for metallic cold cathodes. Voltage limitations greatly favour the use of hot activated cathodes.

(b) For a given brightness the voltage drop of the discharge varies directly with the length and inversely with the diameter: the light output from a lamp of a given voltage drop varies as the square of the length.

The effect of end losses can be conveniently illustrated by plotting, for each lamp voltage, the efficiency of the lamp expressed as a percentage of that of the discharge alone (Fig. 1). It is desirable to have the maximum voltage drop per lamp, or at least to reach the "knee" of such a curve. This is limited by the supply voltage available and its constancy, as well as by the method of lamp starting. For normal mains conditions the supply voltage has to be double that of the lamp, to give adequate stability; for 15- and 20-watt hot cathode lamps a mean voltage of 110 is therefore desirable. Maximum efficiency may have to be waived in favour of using convenient lengths for handling under the stringent conditions of transport service, and this may justify series operation.

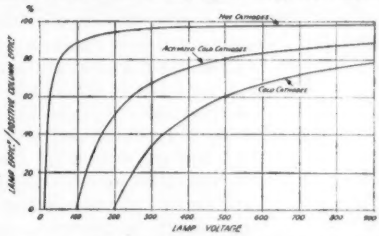


Fig. 1. Variation of fluorescent lamp efficiency with lamp voltage.

(3.1.2) *Life Under Traction Conditions.*

Long life under traction vibration and shock conditions requires the use of lamps of the largest power permitted by lighting requirements. The greater the current, the more robust can be the cathode and the longer generally will it last. At present it is difficult to make robust hot cathodes for currents less than 100 milliamps, and the life increases for increasing currents up to at least

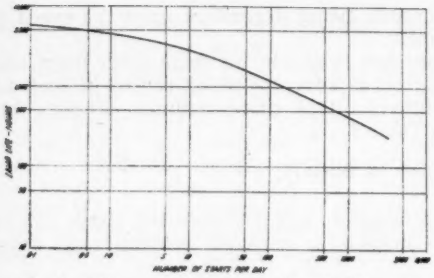


Fig. 2. Effect of frequency of switching on fluorescent lamp life.

one ampere. In contrast cold cathodes are most useful for currents below 100 milliamps.

With metallic cold cathodes, life does not seem to be materially affected by the number of times a lamp is started. With hot cathodes an increased number of starts generally results in a shorter burning life; for example, with average starters on normal 50-cycle supplies a fluorescent lamp may behave as indicated in Fig. 2. This shortening of the life is in general due to positive ion bombardment. The destructiveness of this bombardment with normal hot cathodes is critically dependent upon the condition of emission when current is first drawn from them and, if the service requires a large number of switchings, great care must be taken to adjust the cathode preheating. This should give full emission temperature before the arc is initiated and avoid excess temperature which may cause cathode deterioration by evaporation. It is possible to make hot cathodes which can be bombarded into activity for normal switching service, but preheating still results generally in longer life for repeated switching. "Spiralling" of a number of lamps in an installation on starting is a useful indication of the probability of insufficient cathode preheating.

(3.1.3) *A.C. and D.C. Operation.*

The possibility, where conversion is necessary, of choosing a supply particularly suitable for operating fluorescent lamps has been mentioned in section 2.3. In order to explain the arguments of sections 3.3 and 3.4 it is necessary to study the effect of the supply upon lamp characteristics.

If there is a free choice of obtaining A.C. or D.C., A.C. is to be preferred for the following reasons concerning the lamp:—

(a) Stabilisation losses are lower if chokes or capacitors can be employed.
(b) It is simpler to introduce A.C. circuits permitting the elimination of starter switches, particularly with hot cathode lamps.
(c) There is freedom from cataphoresis end darkening—an effect caused by the migration of mercury ions towards the discharge cathode. While this can be modified to some extent by lamp design, for maximum efficiency and with practical lamp lengths, it is generally necessary to introduce polarity changing mechanisms to operate at a maximum period of five hours.

Fluorescent lamps can be made to operate from very low frequencies up to kilo- and even mega-cycles per second. In general, the efficiency of U.V. generation in the discharge increases slightly with frequency; much of this increase occurs at frequencies up to a kilocycle. This results largely from changes in the voltage and current characteristics. As the frequency increases the lamp voltage drop decreases, and there is a marked improvement in the voltage and current waveforms. This improvement in waveform results in an improved apparent power factor in the lamp, so that all these changes can be summarised graphically by plotting lamp voltage, current, and apparent power factor against frequency, as in Fig 3.

The reduced lamp voltage drop with increase of frequency means that for

a given percentage variation in supply voltage, a lower mean voltage can be used. For a given mains voltage longer and hence more efficient lamps would be possible. In practice it works out to be most economical to use standard lamps, the gain from this lower voltage enabling satisfactory operation to be obtained while permitting a larger variation in supply conditions.

The improvement in waveform is important in that it is possible to use capacitors for stabilising or starting without the destructive peak currents which occur with disastrous effect to lamp life and efficiency on 50-cycle supplies.

Much has been said concerning stroboscopic flicker. While this is considerably reduced by the use of high frequencies ([3]), it is considered that little, if any, trouble would be experienced from the use of 50-cycle supplies in vehicles. It is, however, difficult to assess the effect produced by the movement of printed pages read during travel without a fairly large scale trial. One definite improvement is obtained in this respect: as a lamp fails at end of life rectification often occurs with the introduction of a half-frequency flicker. On 50-cycle supplies this is most objectionable; with high frequencies it is generally not visible, and cases have occurred where the incipient failure of the lamp in this way has been shown by apparent darkening from one end owing to cataphoresis brought about by the rectification.

Turning from high-frequency operation to zero-frequency operation, there are two main lamp characteristics which must be studied. When passing direct current the lamp voltage drop and efficiency are slightly higher. The overall efficiency is, of course, much reduced owing to the use of resistive ballasts.

A main difficulty is that of cataphoresis. This end darkening is not a gradual process, but, as shown in Fig 4, a lamp will operate for many hours

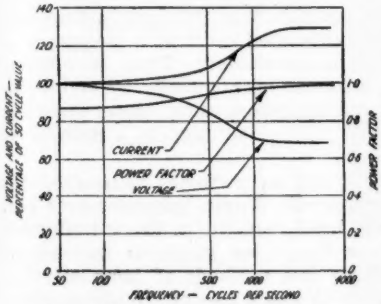


Fig. 3 *(left)*. Electrical characteristics of a fluorescent lamp at different supply frequencies.

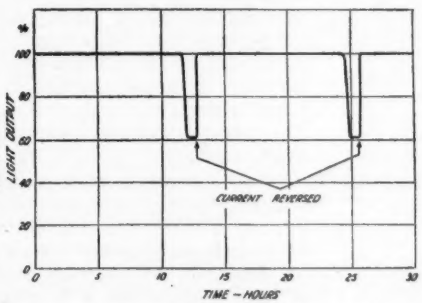


Fig. 4 *(right)*. Cataphoresis in fluorescent lamps.

quite normally and then, as the last of the mercury leaves the anode region, darken from one end to a position in the tube dependent upon many lamp and lantern constants. The growth of this darkening may then occur quickly, as shown. If the polarity and direction of current flow are reversed, the rate at which the dark end effect disappears is even more rapid. With reversal every five hours, it should not normally be encountered. The longer the lamp the more marked the effect, but it may be possible to improve lamps from this point of view.

(3.2) Circuit Characteristics

For transport conditions it is necessary to decide whether the size and cost of control gear can best be limited by adapting lamps to existing supplies, or whether to install conversion equipment and to choose the most suitable supply system.

(3.2.1) *Effect of Frequency*

It has already been stated in 3.1 that stabilisation losses are lower and simpler switchless circuits are possible if A.C. can be used. It has also been shown that increase of A.C. frequency is advantageous to the lamp. Examining this from the point of view of the circuit components (3), the following factors become of evident importance:—

(a) The sizes of chokes and capacitors decrease considerably for frequencies above 50 cycles. This is, in the main, due to the fact that, for a given reactance, both inductance and capacitance are inversely proportional to frequency. Size and cost fall sharply from 50 to 350 cycles, but, for practical reasons, at higher frequencies there is little reduction in size and cost; for frequencies of the order of 5,000 cycles special core material has to be used, thus considerably increasing the cost. Size reduction is particularly important for transport lighting owing to the restricted space for fittings, and size reduction is made possible by reduced losses, which in themselves are a valuable factor. The full possibilities of cost reduction for high-frequency components can only be realised by standardisation, particularly of frequency, to permit efficient production.

(b) While the use of capacitor stabilisation on 50-cycle supplies is of doubtful economic advantage, as the frequency is increased the permissible ratio of capacitance to inductance to give satisfactory lamp current waveform may be increased until at a frequency of about 400 cycles the choke can be eliminated. Thus, an efficient high-power factor lead can be achieved economically by stabilising lamps alternately with chokes and capacitors using starter switches. This arrangement has been used with advantage in a number of ships' installations.

(c) For 50-cycle operation, the use of starter switches minimises the weight and size of circuit components. Lamp improvements permitting a lower starting voltage have resulted in the introduction of switchless starting circuits without too great an increase in ballast size. In addition to these two methods of lamp starting, at high frequencies it is possible to make use of simple resonant starting circuits.

From these general considerations it will be seen that high-frequency operation is favourable to control gear as well as to the lamps.

(3.2.2) *Resonant Circuits*

Since the use of high frequency is relatively novel to the majority of lighting engineers there is no general experience of the operation of resonant starting circuits, so that some explanation of their operation may be helpful. Consider the simple example shown in Fig. 5 (a). A semi-resonant condition can be obtained when the circuit switch is first closed, so that the impedance of the capacitor closely approaches that of the choke. The current flowing

through the circuit is approximately dependent upon the difference between the two impedances and can be made large enough to pre-heat the lamp electrodes. The voltage drop produced by the current passing through the capacitor can be made higher than that of the mains and suitable for starting the discharge through the lamp. When the lamp strikes, the resonant condition is damped out and very little current continues to pass through the lamp cathodes and capacitor. The circuit shown in Fig. 5 (b) is similar in operation but capacitor stabilisation is employed and a choke is connected across the lamp for resonant starting; this generally requires rather larger chokes and capacitors.

Simple resonant circuits may not give satisfactory starting if the supply is switched on suddenly as the lamps may strike without adequate pre-heating of the cathodes. Starting voltage tolerances necessary to take care of temperature and power supply variations may be such that, under favourable conditions, the voltage could start the lamps by positive ion bombardment while the cathodes are still cold. The oscillograms in Fig. 6 (a) show the voltage and

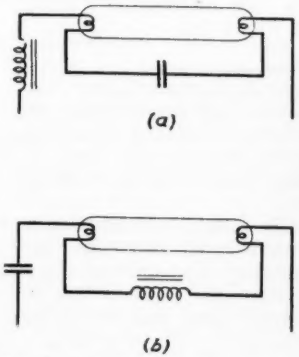


Fig. 5. Simple resonant starting circuits.

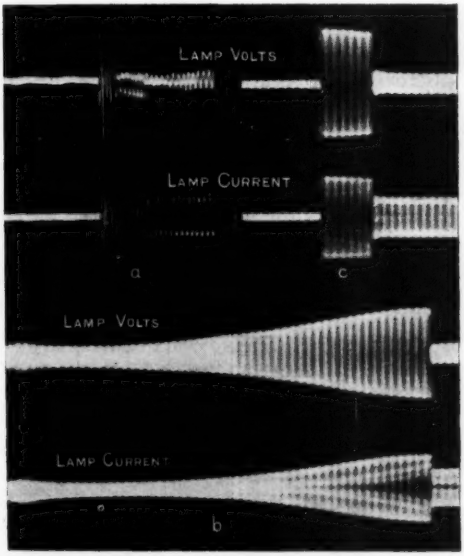


Fig. 6. *(right)*. Oscillograms of a fluorescent lamp starting in resonant circuits.

current waveforms of a lamp which has been started by applying a voltage directly to a lamp connected to the simple resonant circuit in Fig 5 (a). These give some idea of the treatment which the cathodes are undergoing during the starting period; the erratic voltage and current peaks indicate the presence of destructive cathode bombardment.

The condition can be avoided, however, when lamps are operated from a rotating machine, if they are started by running up the machine. The voltage increases gradually and the lamp cathodes are pre-heated before sufficient voltage is applied across the lamps to initiate the discharge. The voltage and current waveforms of a lamp starting in this manner are shown in Fig. 6 (b).

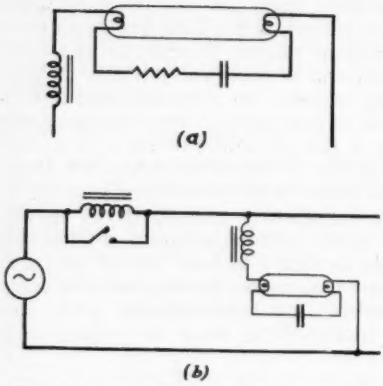


Fig. 7. Improved resonant starting circuits.

If, however, the supply must be available all the time a circuit has to be devised whereby the application of voltage across the lamps is delayed until the cathodes are adequately pre-heated. Two methods of achieving this are shown in Fig. 7; in 7 (a) a resistor is connected in series with the resonant starting capacitor, while in 7 (b) a choke in series with the main supply reduces the voltage applied to the lamp circuits during the pre-heating period. The choke is short-circuited by a time delay relay after two or three seconds pre-heating. Typical lamp current and voltage waveforms produced by this method of starting are shown in Fig. 6 (c).

(3.2.3) *Direct Current*

For D.C. operation thermal switches or electromagnetic relay forms of mechanical starter are used for starting the lamps, and small chokes may be required to produce the voltage surge to strike them. As stated in 3.1, stabilisation is by means of resistive ballasts. Alternative systems have been devised for impulse starting lamps from the higher voltage D.C. supplies but at present these are not suitable for hot cathode lamps.

For D.C. as for A.C. operation, the variation in supply voltage is important since the lamp current must be controlled within definite limits. In Fig. 8 are shown typical fluorescent lamp, resistor, and tungsten lamp characteristics and from the combined stability curves it will be seen that there is less current variation with stabilisation by a tungsten filament lamp due to its baretter

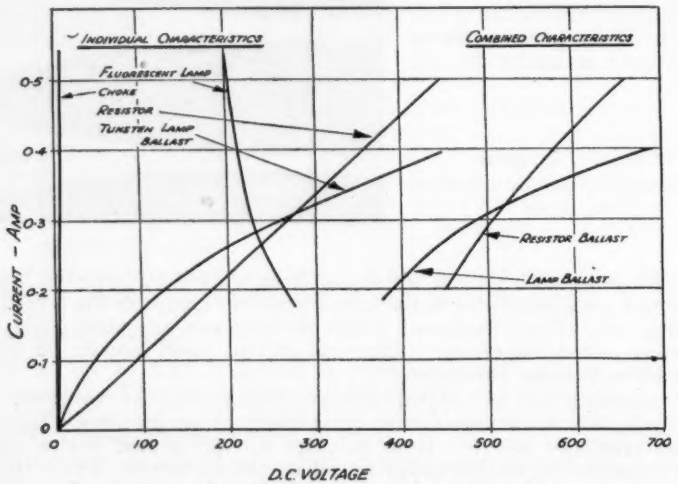


Fig. 8. Stabilisation of fluorescent lamps on D.C.

effect than by a resistance ballast. Hence, for a given current variation, a larger share of the power can be taken by the fluorescent lamp, to achieve greater overall efficiency. A second factor in favour of lamp ballasts is the possibility of utilising their light output. These factors may be weighed against the increased servicing entailed by replacing tungsten lamps. In general a very good compromise is achieved by under-running them, thus giving long life and requiring little servicing but giving sufficient light output for some auxiliary service.

The need for reversing the polarity of the supply has already been stressed and this has been achieved by two methods. As in buildings where D.C. fluorescent lighting is used, it is possible to provide a reversing switch as the local on/off control so that each time a circuit is switched on the polarity is changed. This is practicable only where the lamps are switched at periods of less than about five hours and in transport vehicles this may be possible at the end of each journey. The second method uses an automatic time switch. With changeover times of less than 1-10th second the lamps do not extinguish. Reversal may be difficult in installations where the frame of the vehicle is used as the return lead.

(3.3) Operation from Existing Supplies

Having considered the effect of the supply upon lamp and circuit characteristics it is helpful to return to Table 1 to consider how lamps could be operated from the supplies which are available in vehicles. For simplicity these are arranged in groups.

(3.3.1) *D.C. 12 to 50 Volts*

Although it is technically possible to make fluorescent lamps which will operate on low-voltage D.C. these would be inefficient and such supplies are usually converted to those more suitable.

(3.3.2) *D.C. 50 to 150 Volts*

On 50-70 volts D.C. special lamps, which are less efficient than the standard designs, may be used with tungsten lamp stabilisation and thermal starter switches. Such a system is in use on the New York Central Railway.[4] At voltages above 70 resistance ballasts can be used, and normal 20-watt fluorescent lamps will operate from 110 volts with an overall efficiency of 19 lumens per watt. An interesting example is the special 110-volt lighting scheme installed in the train built for the Royal visit to South Africa.[1, 5]

(3.3.3) *D.C. 400 to 600 Volts*

One problem with high-voltage D.C. traction circuits is the lack of continuity of the supply. For instance, on tramways, breaker gaps are inserted in the overhead distribution line at half-mile intervals and when the tramcar passes these gaps the supply is interrupted for periods ranging from approximately 1-20th second to 2 seconds. Thermal starters suitable for operating at this high voltage have rather a long re-closing time and consequently the lamps may be extinguished for periods up to 30 seconds at the breaker gaps. Series operation with glow starters may give short lamp life.

The difficulty has been met by devising special starters combining adequate pre-heating with rapid re-striking. One type[6] shown diagrammatically in Fig. 9 (a) uses resistance/capacity timing of an eletromagnetic relay which may control a number of lamps. When the mains switch is closed the supply voltage appears across relay coil A, the capacitor across this coil charges and the relay is energised, closing contacts A. Coil B is then energised, contacts B

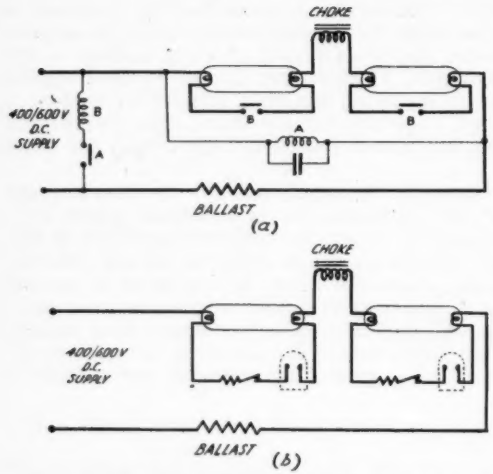


Fig. 9. Starting circuits for 400 to 600v. D.C. traction supplies.

close, and the pre-heating current flows through the choke and lamp cathodes. The voltage then applied across coil A is reduced to that of the lamp cathodes. The capacitor discharges, delaying the opening of relay A for about one second and the opening of contacts A de-energises coil B and contacts B open. A surge is produced by the interruption of the current through a small series choke to strike the lamps. For rapid interruptions of the supply of less than 1-10th second the starter will not operate and the lamps are not extinguished. If the supply interruption is of longer duration the starting operation is repeated.

Trials have recently been made using experimental canister starters[7] which allow quick re-striking. Connected as shown in Fig. 9 (b), the desirable characteristics of both glow and thermal starters have been combined, the glow action giving rapid re-striking, the thermal action adequate pre-heating. Although lamp striking is not quite as uniform as with magnetically operated starters good results are obtained with considerable simplification and reduction in cost. Two 30-watt fluorescent lamps will operate from a 500-volt circuit with an overall efficiency of 18 lumens per watt.

(3.3.4) *A.C. 110-115 volts. 250-1600 Cycles*

Lamps may be operated from this supply with choke stabilisation and resonant starting circuits. If, however, weight is of paramount importance, as in aircraft installations, starter switches may be preferred.

(3.4) Conversion Equipment

Reliability and efficiency are two important requirements of conversion equipment. Two practical forms are rotary machines and vibrator or commutator inverters.

(3.4.1) *Rotary Machines*

Motor alternator sets and rotary inverters delivering up to 3 KVA at frequencies from 250 to 1,000 cycles are the most common form of conversion equipment at present used for fluorescent vehicle lighting. Small inductor type alternators can be made cheaper and lighter in weight than salient pole alternators giving an advantage in favour of high frequency. For ratings of approxi-

mately 1 KVA, the cost of the inductor machine is about half and the weight one-third that of a salient pole alternator.

A totally enclosed motor alternator weighing 173 lb. which operates from 24v. batteries and delivers 800 watts at 110 volts, 400 cycles, is shown in Fig. 10; it is specially designed for fluorescent lighting and will supply 34 20-watt lamps (8).

Fig. 10. High frequency motor alternator for 24v. battery supplies.

Under service conditions an efficiency of 68 per cent. has been measured giving an overall efficiency of 18 lumens per watt D.C. This is achieved with a speed of 3,000 r.p.m. to reduce noise and to give that reliability with minimum maintenance always associated with train lighting equipment. Similar machines have been designed for ratings as low as 300 watts; below this size the efficiency decreases rapidly.

(3.4.2) *Vibrator and Commutator Inverters*

For efficiency, inverters of the vibrator or commutator type seem attractive but fluorescent lamp circuits introduce commutation problems. Practical vibrators are at present limited to a maximum frequency of about 110 cycles and careful circuit design is necessary to obtain a satisfactory current waveform. They may be useful for applications where the weight of rotary machines is prohibitive or where complete lighting units containing the means of conversion are required. Their field of usefulness seems to be particularly for ratings of 15 to 300 watts, but their practical application has been limited by unreliability and the need for replacement of vibrator elements.

Higher frequency supplies are possible using rotary commutators but their peculiar problems have not yet all been solved. The study of the reliability of operation of these inverters with fluorescent lamp circuits may lead to their wider application.

Fig. 11 *(left)*. Combined aircraft ventilation duct and lighting unit for bare fluorescent lamps.

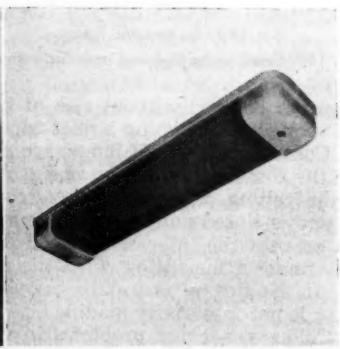


Fig. 12. Lighting unit with reeded plastic cover for 15w. fluorescent lamp.

(4) Lighting Equipment

(4.1) Lamps and Lanterns

To conform with the different styles of vehicle interior and lighting layout, the lighting units themselves exhibit a variety of characteristics. They are all ceiling or wall mounted, as suspended units would not be suitable in a moving vehicle and two broad categories seem to be developing, namely, bare lamps with no directional properties and enclosed units with a diffusing or refracting cover. Directional reflectors have been employed in one or two experimental installations but not to any great extent.

Bare lamps need to be sited carefully to avoid undesirable brightness contrasts or an obtrusive appearance, but attractive interior decorative schemes can be designed of which the lighting units are an integral part. In the example shown in Fig. 11, the control gear is mounted above the lamp in a housing which also forms part of the ventilation system of a pressurised aircraft. The louvres which were fitted experimentally to reduce the conspicuity of the long light source have not been found necessary in practice.

A more normal design is a totally enclosed unit (Fig. 12) which is less vulnerable to accidental damage or pilfering and is easier to clean. The shape and size of the lantern must obviously be arranged to harmonise with the style of the interior decoration and the space available. A wide variety of designs was introduced into early installations and this favoured the use of sheet metal and plastic sheets for most of the parts, as these materials could be formed economically for relatively small numbers of units. As the designs develop, however, a few standard forms are emerging and other methods of construction are practicable. Aluminium castings are finding increasing favour due to their robustness which is useful in vehicles subject to severe vibration and shock. The cast body and frame of the bus lighting unit of Fig. 13 enable quick-acting

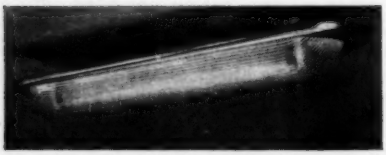


Fig. 13 (*above*). Lighting unit with cast body for 15w. fluorescent lamp.

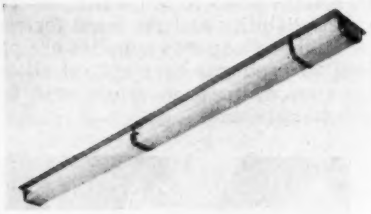


Fig. 14. Continuous lighting unit for tramcar.

fixings to be used without risk of faulty operation due to distortion in service, and they give the fitting a neat appearance.

Continuous lines of lamps are a feature of some vehicles such as tramcars and the construction shown in Fig. 14 may be adopted. The lamps are mounted on the ceiling or in a shallow trough reflector with a formed plastic cover. Attractive tinted patterns may be applied to the cover to reduce the brightness and prevent the interior details from being obtrusive. Their main purpose is to harmonise the fitting with the decorative scheme when the lamps are not alight; the tinting is usually so slight that the colour of the light from the lamps is not materially modified.

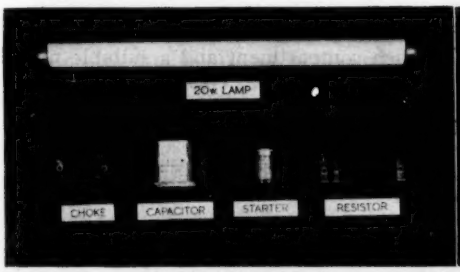
Colour rendering problems in vehicles are practically identical with those in other interiors and the restricted lighting levels favour the use of the warm white lamp colour. With the difference in illumination from daylight and the artificial lighting a warm white fluorescent installation blends easily with day-

light, an important factor where the two systems alternate as when the vehicle passes through tunnels.

(4.2) Control Gear

Just as the particular requirements of transport lighting lead to systems which are different from those of normal industrial or commercial practice, so the control gear designed for this service exhibits special features. Small size and weight are often important factors, while the unusual supplies require different electrical characteristics in the gear.

With high frequency operation, it is practicable to design small, light chokes even though the loss must be kept low to make the best use of the restricted power available. Capacitor materials can also be used more economically at high frequencies as described in 3.2.1. The small choke and capacitor shown in Fig. 15 are the complete circuit components required to strike and stabilise the 20-watt 1½-in. diameter fluorescent lamp. The choke dimensions are 1⅝ in. by 1⅞ in. by 3¼ in., and the weight 11 oz. The capacitor size is 1⅞ in. by 1⅞ in. by 2½ in., and its weight 7 oz. If weight is of paramount importance, the capacitor may be replaced by the standard starter shown, to form the conventional A.C. circuit. Individual power factor correction may be needed with some high fre-



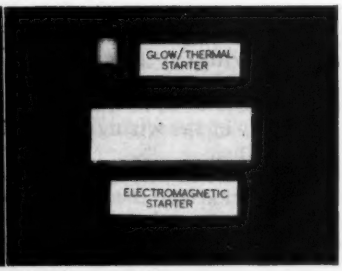


Fig. 15 *(left)*. Circuit components for 20w. fluorescent lamp.
Fig. 16. Starters for 400 to 600v. D.C. traction supplies.

quency supplies, and the additional capacitor then required is similar in size and weight to the one illustrated.

High frequency power supplies need to be used with care when near metal structures, owing to the possibility of noise from the metal by induction. While no trouble should normally be experienced with wiring, circuit components, such as chokes, may cause noise in adverse conditions, and it is recommended that in particularly quiet situations a clearance of ½ in. should be left between the choke and any metal work. It is possible to detect leakage flux around some capacitors, but this is usually so small that it can be neglected.

On a 120-volt D.C. supply a resistor must be added to the starter/choke circuit, and its accommodation must ensure that the heat generated is dissipated effectively, while its exposed windings must be properly protected.

On 400/600-volt D.C. circuits the experimental glow/thermal starter or the electromagnetic starter in Fig. 16 are used as described in 3.3.3. Both require a choke to provide a striking surge to operate two 30-watt or four 20-watt fluorescent lamps, and this may be of the same size as the 20-watt stabilising choke, while the ballast may consist of a resistor or three 40-watt traction filament lamps.

(5) Applications

(5.1) Steam Trains

The interior layouts of most main line steam trains in this country are either compartment or saloon coaches, but there are special cases, such as buffet cars, where the layout is very varied.

Although the lighting requirements may be similar in compartment and saloon coaches, different methods of achieving the finished results may be employed for practical reasons. Thus in a compartment, the number of lighting points is determined by the need for light in several different positions, whereas a saloon coach may employ general lighting, one point serving a group of seats. In a compartment general lighting, which is necessary for passengers entering or leaving, is conveniently obtained from lamps mounted on the ceiling. This is not the ideal arrangement for reading, although it is often used quite successfully, three 20-watt fluorescent lamps providing 10 lumens per sq. ft. on the seats and 7 lumens per sq. ft. on the 45 deg. reading plane. Reading illumination can best be obtained from lighting units on the luggage rack or above the seats. Two 15-watt lamps on each side provide about 12 lumens per sq. ft on the reading plane, and an experimental installation has been in service using a specially designed front rail for the rack to accommodate the lamps

The usual method of converting the 22- or 24-volt. battery supply on steam trains to 110 volt 400 cycles A.C., is by means of the motor-alternator described in 3.4.1. With five 15-watt lamps in each compartment and a suitable number in the corridor, etc., the battery load is 1,200 watts. This exceeds the power normally available as indicated in 2.3 Table 1, and, together with the increased complexity of the wiring, has hampered the general adoption of rack or back-of-seat lighting.

Filament lamps in concentrating reflectors or lens units (Fig. 17) may have an application for the rack or back-of-seat positions as their inherently lower efficiency should be outweighed by the ability to focus the light into the most useful area. More overhead light is, however, desirable to avoid high contrasts between the local brightly lit areas and the general surroundings. Some care is also needed in placing small sources, such a filament lamps, to avoid hard shadows occurring on the printed page, due to obstruction by passengers' heads. The larger fluorescent source has an advantage here, requiring less exact placing.

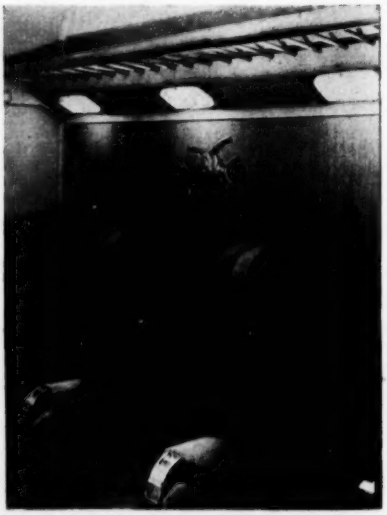


Fig. 17. Showing filament lamps used in back of seat positions.

Saloon coaches permit a certain latitude in the arrangement of lighting units, and pleasing layouts may be adopted without detracting from the effectiveness of the lighting. Fig. 18 is historically interesting, being a general overhead system operating experimentally from a 500-cycle motor alternator installed on a coach in 1939. The substitution of these early 15-watt

Fig. 18. Pre-war fluorescent installation in a saloon coach.

fluorescent lamps for the existing tungsten filament lamps increased the illumination from 4 to 8 lumens per sq. ft. with an additional battery loading of one-third.

Dining cars (Fig. 19) need special consideration in that light is required mainly on the tables rather than on the reading plane, and shadows cast on to white tablecloths are sometimes objectionable. Local lighting points, one above each table are a desirable supplement to the general overhead lighting.

It should be remembered that a difficult task is performed by waiters negotiating gangways while the train is in motion, and from their point of view the lighting must be adequate and free from glare.

(5.2) Electric Trains

The interior layouts of most main line electric trains are similar to those

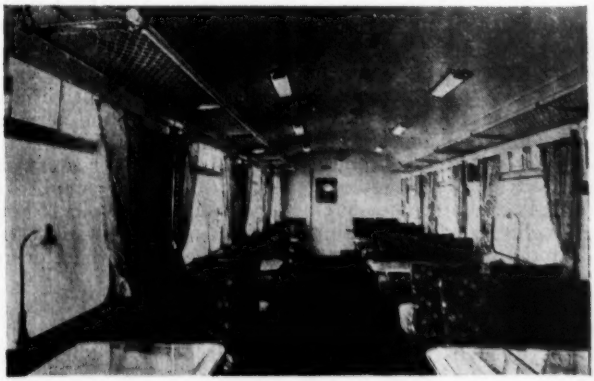


Fig. 19. Interior of a dining car.

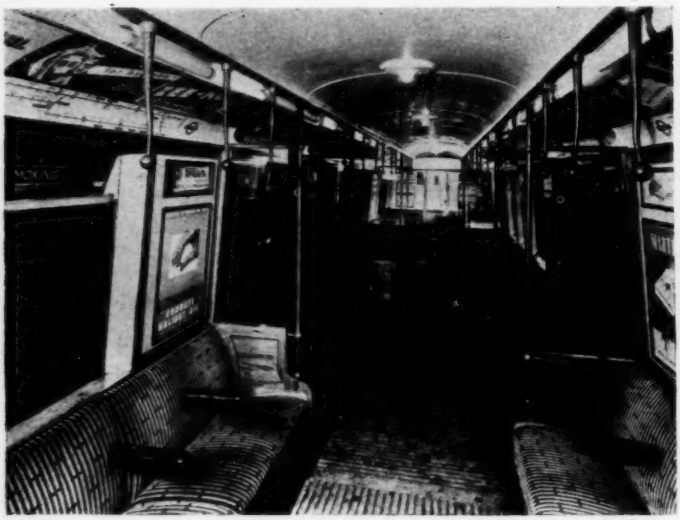


Fig. 20. Fluorescent installation in a London Transport electric train.

in steam trains and the same requirements have to be satisfied. Owing to the greater power available from the traction supply, some of the limitations applying to the battery-supplied coaches are removed and a higher level of illumination is possible.

Ceiling mounted lighting units avoid the possibility of passengers interfering with higher voltage D.C. circuits. Enclosed fittings are desirable, and continuous lines can often form a neat and attractive solution to this problem.

An alternative supply system has been considered for electric trains, using a self-excited motor alternator designed to operate from the traction supply. For short time gaps the inertia of the machine helps to maintain the lighting, and as the lamps operate from 110 volts, insulation and safety problems do not arise. Where full standby lighting is required a battery is necessary, and the lamp supply system is similar to that for steam trains.

Underground trains are quite different in layout and function. Shorter passenger journeys are involved, and a brisker atmosphere exists so that the lighting must be designed more from the point of view of aiding movement than creating a restful atmosphere. The low brightness of fluorescent lamps in conjunction with the light-coloured decoration permits lamps to be installed bare and they form an attractive feature of the L.T.E. coach interior shown in Fig. 20, where the illumination is 10 lumens per sq. ft. The power for lighting is derived from a motor generator/alternator supplied from the D.C. traction circuit, the alternator having an output of 110 volts 850 cycles and the generator 50 volts D.C. for operating the train control circuits.[1] The generator output is required continuously, and the lamps are therefore started by one of the methods shown in Fig. 7.

(5.3) Tramcars

Although passenger transport is being handled more and more by buses

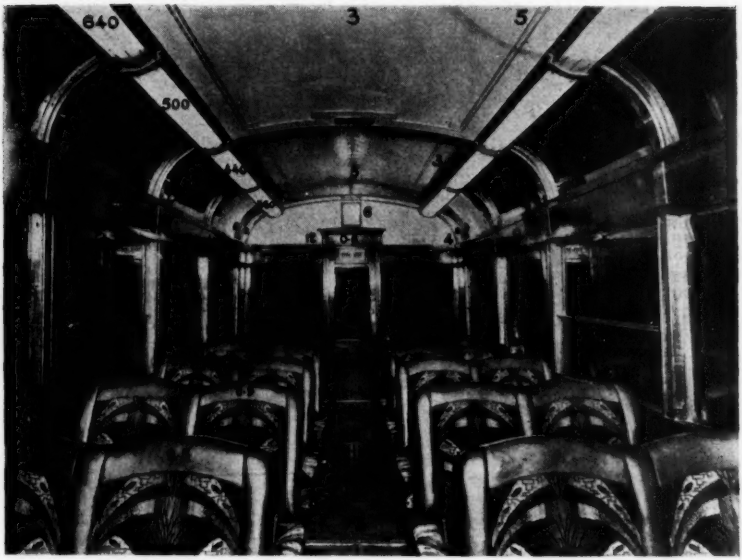


Fig. 21. Brightness distribution in a tramcar fluorescent installation. (Figures in foot-lamberts.)

and trolleybuses, tramcars are still important in many cities, and have an economic place in the system. Possibly one contributory reason for their replacement has been the better appearance of the newer types of vehicle, but modern tramcars differ greatly from their early counterparts, and modern lighting can do much to give a new look even to an old interior. In the past, the ample power supply enabled a good level of illumination to be provided, but the prevalence of bare lamps did not enhance the general appearance. Attempts to reduce glare by diffusing glassware were successful only at the expense of efficiency, but nevertheless, several attractive systems were developed.

The car shown in Fig. 21 is one in which 30-watt fluorescent lamps have been substituted for the filament lamps without modifying the lighting layout, and they fit almost ideally into the decorative scheme of the car. The improvement has been threefold—increased illumination, better colour, and reduced brightness contrasts. A more efficient optical system has resulted from substituting lightly diffusing covers for the heavily patterned ones, which were previously used to break up the patchy effect of the filament lamps; the interior illumination has been raised from 2 to 10 lumens per sq. ft., with a brightness distribution as shown. An interesting feature is the use of the 40-watt ballast lamps to illuminate the indicators as suggested in 3.2.3, enabling the improved lighting to be obtained while halving the power taken from the line. The glow/thermal starters described in 3.3.3 are used to start the lamps, and are mounted together with the lampholders on secondary insulation.

In an interesting experiment(9) 20-watt lamps have been operated directly from the traction supply and from a high frequency motor alternator set in the same tramcar. The increased capital cost and weight of the machine generally favours the direct D.C. system.

Fig. 22. Fluorescent installation in a trolleybus.

(5.4) Trolleybuses

Although the severe restriction of a battery supply may not apply to lighting systems in trolleybuses operating directly from the traction supply, space limitations act in the same way to limit the number of lamps which can be installed. Where batteries are used, a motor alternator set converts the 30-volt D.C. supply to high frequency A.C. For metal bodied trolleybuses only low voltage lighting is normally allowed (10), but special dispensation has been given by the Minister of Transport where fluorescent lighting has been installed.

Almost flush-mounted lighting fittings are appropriate, and although little can be done to control the light efficiently, the service illumination in the installation shown in Fig. 22 is 15 lumens/sq. ft. Accommodation of the control gear also presents problems, and some ingenuity must be exercised to conceal it behind the cornice plate—the most convenient place to prevent long wiring runs—or to group the components in boxes in suitable positions close to the ends of the wiring channels. Where traction voltage is used direct and the control gear described in 3.3.3 has to be accommodated, the former method has much to recommend it, but noise due to metal parts near the chokes in a high frequency system may be more easily avoided by grouping them outside the saloons.

Boarding, alighting, and mounting the stairs are more frequent on trolleybuses than most other vehicles, and the higher acceleration makes these operations more difficult. Lighting of the stairs and platform, which are often crowded, must therefore be carefully designed to avoid any chance of stumbling due to bad visibility. The problem is difficult because the road just below the platform should be illuminated, and passengers tend to cast shadows in just that area. A lighting unit can be placed in the ceiling over the edge of the platform to avoid glare to passengers entering, while lighting the edge and the road. Another lighting point is required above the platform to illuminate the bottom stair. The large size of fluorescent lamps makes them very appropriate for such duties, as chance shadows are less sharp, and therefore not so likely

to confuse passengers; if the longer fluorescent lamps are installed, one lamp can serve for the two purposes.

(5.5) Buses and Coaches

Apart from a general similarity of interior layout, buses and coaches vary considerably in the details of their construction and the lighting systems are likewise diverse. Fluorescent lamps have been applied to one or two different types. Shortage of power, which under stationary conditions depends upon battery capacity, has led to the use of 15-watt lamps in sufficient lighting points to light the interior evenly. It is usually convenient to accommodate lamp control gear behind the cornice plate where this is possible, but it becomes a matter of individual design in each case.

Power for lighting is obtained from one of the smaller units described in 3.4.

(5.6) Aircraft

The very rapid development which is now taking place in aircraft has made it difficult to introduce a new feature, with its attendant complications. Extreme limitations of space and weight have meant special consideration in each case of the complete system from power supply to lighting units, to find the fluorescent arrangement giving the best return for the inevitably increased weight as compared with filament systems.

Where a suitable power supply is available such as in an aircraft powered with 120 volt D.C. the simplest lighting system can give very good results and

Fig. 23. Bare fluorescent lamp installation in the cabin of a passenger aircraft.

provide sufficient illumination with a small increase in weight (Fig. 23). Here the ventilating grille has been designed to accommodate the control gear described in 4.2 and the lamps are supported below it, end covers enclosing the lampholders. The total weight of the lamps and gear is 40 lb., the additional weight of the fitting due to combining the functions of ventilator and reflector being small. The service illumination is 12 lumens per sq. ft.

It is fortunate that battery supplies of 24 volts are less common nowadays because the additional machine to generate higher voltage A.C. or D.C. is an

almost crippling addition to the weight. Where it can be allowed, however, a very satisfactory lighting installation is possible. An alternative would be to use a machine normally kept as stand-by for radio or radar, and in this case the type and amount of power for lighting would be determined by the size of such a machine. The supply is usually at a high frequency, and the control gear could be built into the lighting units.

In short-distance "feeder" aircraft, general cabin lighting which mixes well with daylight and avoids the dark ceiling caused by the customary small, low windows, is all that is required. The level of brightness inside the cabin should be as high as possible to reduce glare when flying above sunlit clouds. For longer journeys, particularly at night, some passengers may wish to sleep and others to read. Some form of control over the general lighting is clearly desirable for the sleepers, whereas the readers want, if anything, a higher illumination on the page. Local lighting can fulfil this function and small filament lamps in concentrating units avoid spilled light on adjacent passengers. Chair-head lights have been designed for this purpose, and while seeing conditions—a bright page surrounded by a dim cabin interior—may not be ideal, they do at least enable the two requirements to be satisfied. An alternative scheme which has been used in the United States is a series of ceiling-mounted spotlights focused on individual seats and controlled by switches on the chairs.

(6) Conclusions

Most of the fluorescent lighting installations described are similar to the filament schemes preceding them. This does not mean that a fluorescent lamp merely replaced a filament lamp, but that the principle of lighting has not been changed, greater evenness of illumination being obtained with the larger, more efficient sources. It is to some extent due to introducing them into existing vehicles.

The system of converting low voltage battery supplies to high frequency A.C. has been most successful, but where existing D.C. supplies suitable for operating fluorescent lamps are available, direct operation has economic advantages. The degree of success achieved can be judged by the fact that for each watt of primary power approximately twice the lumens are now obtained from fluorescent as from tungsten filament lamps. Owing to the reduced degree of diffusion necessary with the lower brightness sources for equally pleasing lighting, the illumination can often be further increased several times. With this new lighting tool an average illumination of 10 to 15 lumens per sq. ft. is generally attained.

Having established fluorescent lamps as a successful means of lighting vehicles it is now possible to hope that their full potentialities may be exploited in new designs.

There seems to the authors to be some scope for considering the large sources as part of the structure, and not simply as annoying additions to an already tightly designed assembly. An example has been mentioned in one of the railway coaches where the luggage-rack rail is also the lighting fitting with directional properties, and, in aircraft, combining ventilators and continuous lighting reflectors. The greater freedom which the high efficiency and low brightness of fluorescent lamps should give—once the disadvantages of having to use conversion equipment and control gear are fully understood and overcome—will, we hope, contribute much to the amenities of travel.

Acknowledgements

The authors wish to express their appreciation of the help given by transport authorities in providing facilities for field tests and in permitting the

publication of photographs illustrating practical applications. Figs. 11 and 23 are reproduced by permission of Handley Page, Ltd.; Fig. 17, Pressed Steel Co., Ltd.; Fig. 18, British Railways, London Midland Region; Fig. 19, British Railways, Southern Region; Fig. 20, London Transport Executive; Fig. 21, Blackpool Corporation; Fig. 22, St. Helens Corporation. Our thanks are due to Mr. L. J. Davies, Director of Research of the B.T.H. Co., for permission to publish the paper.

References

(1) International Commission on Illumination, Eleventh Session in Paris, 1948.
(2) L. J. Davies, H. R. Ruff and W. J. Scott, Jour. I.E.E., Part II, **89,** 447 (1942). J. N. Aldington, Trans. I.E.S. (London), **7,** 57 (1942), H. G. Jenkins and J. N. Bowtell, Trans. I.E.S. (London), **8,** 61 (1948).
(3) R. Maxted and J. N. Hull, Trans. I.E.S. (London), **10,** 220 (1945). J. H. Campbell, Illuminating Engineering, **43,** 125 (1948).
(4) W. S. H. Hamilton, Electrical Engineering, **61,** 179 (1942).
(5) Railway Gazette, **85,** 606 (1946).
(6) R. V. Mills, M. G. Clarke, H. R. Ruff and B.T.-H. Co., Br. Pat. Appl. 32384/46.
(7) R. V. Mills, H. R. Ruff and B.T.-H. Co., Br. Pat. Appl. 23,102/47.
(8) A. Mandl and G. R. Mason, Metropolitan-Vickers Gazette, **22,** 323 (1948).
(9) Transport World, **C,** 542 (1946).
(10) M.O.T. Trolley Vehicles Memorandum (1948).

Discussion

Mr. W. S. GRAFF-BAKER, remarking that he regarded himself as a transport engineer, having had both a mechanical and an electrical training, said that one of the transport engineer's jobs was to wrap up the products of his undertaking in an agreeable form. They were trying to sell transport, and it was customary, commercially, to regard the packaging of the article as a great factor in its sale. The endeavour was being made to sell transport in the best possible packaging. The packaging included the appearance and comfort value of the car. These were very important, and lighting had to take its place not as a specific and a single thing, but as a part of the total design. In other words, whereas in the old days a car was produced and the lighting and other fittings were screwed on afterwards, it was necessary to-day to design the fittings into the car, whether they be lighting or any other fittings.

London Transport had aimed at providing a standard of lighting in its cars which was better than people usually had at home. The problem, however, was not a simple one because there were two kinds of traffic to be considered. There was the traffic during the middle-day period when people had time to look at the car and could also read in comfort. There was also the rush traffic morning and evening, when so many passengers had to stand and had little opportunity of looking at the car.

Reference was made in the paper to the reduction of heat due to the use of the fluorescent lamp and, of course, reduction of temperature was a consideration. In the older types of car there were 30 60-watt lamps, and these gave off sufficient heat to keep the people over-warm in the summer! At first the cars were lighted with 16-c.p. carbon filament lamps. These were followed by tantalum lamps, and later by tungsten filament lamps. Now there was the fluorescent lamp. In the past the lamps had been arranged in various ways in order to try and give a good reading light, not only to the passengers who were sitting down, but also to those who wished to read their papers when they

were forced to stand. It was very difficult to avoid shadows on one's paper from the other man's—or even from the particular passenger himself. With later lighting systems, curiously enough, they had reverted to the old idea of lighting along the cant rail of the car, with two parallel lines of light arranged as far as practicable in the architecture of the car.

Reference had been made to the lighting of compartment stock trains by lights under the luggage rack, and in this connection he showed a slide of an arrangement which was considered in 1935. This was a rather special type of compartment car, and the lighting was partly in the roof and partly by fittings under the rack.

Continuing, he said that the authors had referred to weight limitation, and particularly to the weight of converting equipment, but that was really not so difficult as it might seem. An Underground train on the District line took 80-watt-hours per ton-mile to run the service. If the conversion equipment weighed a ton it would only have to save 80-watt-hours per mile to provide current to carry itself along, but such equipment in fact did not weigh one ton. An equipment weighing 12 cwt. would serve two cars, and therefore, from the point of view of weight, the position was not as bad as it might seem.

The biggest "weight" that fluorescent lighting had to carry was the financial burden of the capital cost and the running cost; not the running cost in current but the running cost in lamps. The capital cost of the fittings and conversion equipment was important. He did not believe the present costs would remain as high as they were, and with the realisation that the only way to get something done was to make a start, the use of fluorescent lighting on the District and Metropolitan line new stock had been decided upon. He hoped to have 200 cars fitted with fluorescent lighting, but, when all the figures were added up, it was not inexpensive. Manufacturers, designers, and users must endeavour to get these figures down. He was certain that until the cost was brought down we should not find the sale and usage of fluorescent lighting increasing at the rate which they would all like.

Table I in the paper gave the limitations of power supply which, in certain aspects, he frankly could not understand. For instance, he could not understand why it was suggested that an electric train using the 600-volt D.C. supply for lighting would only have available 3,000 watts for two coaches. That was quite clearly wrong. There was no limitation—beyond the ordinary common-sense economy—in the amount of power that could be supplied from the third rail or overhead wires for lighting. On steam trains, of course, the limitation was perfectly clear and caused one to indulge in the fascinating pastime of trying to get a quart out of a pint pot. On trolley-buses there was no limitation with 500-volt D.C. supply, but on ordinary buses there was a limitation because of the size of the generator that was necessary.

The use of D.C. fluorescent lighting on traction circuits he thought was fundamentally a mistake. In the first place, what was meant by a traction circuit? It meant one in which the voltage varied from 630 volts just outside the sub-station to a figure something of the order of 525 volts or less at a point some distance from the sub-station when the train started. In his view, that was not a satisfactory circuit for filament lamp lighting, and for fluorescent lighting it would be even more unsatisfactory.

The rotary machine that had been referred to was not adopted to deal with any lighting at all in the first instance. It had been decided to adopt 50 volts for the brake circuits, door circuits, etc. It was a nice round figure and did not give too much trouble to keep insulated comfortably. To provide that, it was necessary to charge batteries through a resistance or put in a motor generator,

and it was decided to have a motor generator. It was found it would be necessary to have a 1-kw. machine for the purpose, but anyone who had had experience of such a machine running on traction voltage, which might change instantly from the highest to the lowest, would appreciate that this was not a very attractive machine on the motor side. Therefore, it was thought it might be better to have a larger machine and to put the lighting on 50 volts. The trains running, for instance, on the Northern line to-day were lighted with 50-volt lamps, and the capacity of the motor generator was increased from 1 kw. to 5 kw., to deal with two cars. The effect of that was to get a more economical and robust lamp from the point of view of life and a better coloured light.

Then fluorescent lighting came along. They started with 600 volts D.C., but did not find it satisfactory. As a consequence they had a generator, working at a frequency of 1,300 cycles, built for a pair of experimental cars. It was then found possible to put in the standard D.C. motor-generator, and by means of a special winding to produce A.C. at the very attractive frequency of 850 cycles. That was the genesis of the generator described in the paper.

Another thing that had to be taken into account was not to have an A.C. frequency on the train which could in any way interefere with the A.C. track-signalling system, because if current went adrift it might result in signals being green when they should be red!

Further, the rotary machine gave some protection to the lamps against the gap which was unavoidable on the third rail system. The lighting was carried on by the inertia of the motor-generator and the lamps did not go out because the motor-generator had stopped, while, if the gap were long enough to let the motor-generator slow down too far, the lamps were restarted by the motor-generator running up to speed.

London Transport had decided to adopt the 2-ft. lamp in preference to the 4-ft. lamp, on account of greater ease of handling.

Remarking that the lamp and its fitting should form part of the architectural structure of the car, he said that, personally, he was prepared to modify the design of the car, as such, to achieve that object, if that should be necessary. The lighting was too important a part not to be dealt with as part of the whole.

On the question of the collection of dirt by fittings, even enclosed fittings, he said he knew of no exception whatever. The fittings might start with being dustproof, but they did not end up by being dustproof, and they gradually got dirtier and dirtier. Cleaning cost money, and the importance of this could be imagined in considering 3,700 coaches each containing 30 lighting fittings. This cost was a burden which had to be reduced, and in order to reduce it as much as possible he was quite unrepentently using bare lamps.

Slides were shown, illustrating a filament lamp in a square shade at the corner of a rectangular arrangement of fluorescent lamps to provide emergency lighting in a coach should the fluorescent lighting fail. Another showed a sketch illustrating the manner in which the fluorescent lamp equipment is disposed in the ceiling, with facilities for access to the auxiliary equipment.

Other slides depicted coaches on the New York subway showing fluorescent lighting on the newest cars. In this case, it was stated there are three rows of cold cathode tubes worked off D.C.

Other slides relating to the use of fluorescent lamps in train coaches were also shown.

In conclusion, Mr. Graff-Baker apologised if he had seemed to give another paper rather than discuss the authors' paper.

MR. E. W. TAILBY said the old L.M.S., had carried out experiments with fluorescent lighting and had some small experience. Whilst he believed that this type of lighting would ultimately prove acceptable to railway engineers, he hardly thought that at the moment they could favour it. In the first place, there must be the utmost simplicity and robustness in train lighting equipment, but the introduction of the fluorescent lamp necessarily brought with it a certain amount of additional apparatus and even a variety of gadgets which were not altogether desirable from the point of view of simplicity. However, it must not be thought that because of that railway engineers were prejudiced against the use of fluorescent lighting for railway coaches.

The authors had shown quite clearly their appreciation of the difficulties to be faced when attempting to apply this form of lighting to axle-driven equipment. In this case, resources were very restricted and although it had been suggested that the introduction of fluorescent lighting would enable them to have more in hand in the way of availability, in practice, experience so far did not justify that view. A generous allowance for a fluorescent lamp of 15 or 20 watt was 30 lumens per watt. It was suggested in the paper that the inverter efficiency could be taken at about 68 per cent. It might be, he said, that there were inverters available which had that efficiency, but he would prefer to put the efficiency at about 62 per cent. in order to allow for variability of loading. The lamp efficiency, allowing for losses in the choke, was round about 85 per cent., so that the combined efficiency of the inverter and lamp was about 53 per cent., which meant that for every 15-watt lamp the energy to be taken from the generating equipment was about 28.5 watts, which gave an overall lamp efficiency of about 15.8 lumens per watt. On the other hand, with the 60-watt 24-volt lamp, which had a short stubby filament, and, as in his case, was used at about a half or one volt over its normal rating, a life of about 2,000 hours was frequently obtained, the average lumen output being about 15 lumens per watt. So that for the privilage of introducing the fluorescent lamp at a cost of between £250 and £300, there was a gain of about 0.8 lumen per watt, and he suggested that that would not justify an extensive application of fluorescent lighting on railway coaches. He was quite certain that the lamp makers would produce more efficient lamps, but he did not expect to get a greater efficiency from the inverter, and he had little faith in the vibrator which, he had been told, could give a better efficiency. That was the position as he personally saw it at the present time. Railway engineers were interested in fluorescent lighting, but they did not feel at the moment that they were getting any more than change for sixpence and having to spend a considerable sum of money in the process.

Commenting on the difficulty of keeping fittings clean, he said he did not favour screening the fluorescent lamp because the intrinsic brilliancy was lower than that of a filament lamp, and therefore more acceptable unscreened, and enclosed fittings were difficult to maintain in a sound condition. Nor did he like the use of louvres, especially on steam trains which were dirtier than electric trains. He thought, therefore, that we should have to be satisfied with bare fluorescent lamps for the time being. It might be that the cold cathode tube would be more suitable for saloon coaches than hot cathode tubes, and he was hoping to experiment along these lines.

In conclusion, he said that whilst the railway authorities were anxious to help in the matter of detailed tests, he did not feel at the moment that the application of the fluorescent lamp to railway coaches, on which the current had to be converted, was justified on a large scale.

DR. J. W. STRANGE said that whilst criticisms of the use of short hot cathode lamps of the type described on grounds of low efficiency and high capital cost of equipment were justifiable at the present moment, he felt that too little attention was paid to the positive advantages of this form of lighting. It was not sufficient merely to say that it was modern.

Arising out of the photographs shown by Mr. Graff-Baker of coaches on the New York Subway, he said he had had the opportunity of seeing this last spring, and he agreed that the general design of the coaches was a strong contrast to what we were used to in London, and it seemed very primitive, although the lighting system had many points of interest. This use of fluorescent lighting on the New York Subway was fully described in a paper by C. I. Brady, jun., R. G. Slauer and R. R. Wylie, in "Illuminating Engineering" (43, 1948, p. 50). This paper gave some efficiency figures which were interesting. The over-all efficiency at 100 hours of the 4-ft. cold cathode lamp running direct on 625 volts D.C., which avoided the loss of efficiency in the converter, was 14.5 lumens per watt, and in the case of the 6-ft. lamp, the over-all efficiency was given as 23 lumens per watt. The estimated life was 8,000 hours. Therefore, if it were possible for other reasons to use the 6-ft. lamp, a higher efficiency and longer life could be claimed in making comparison with the low voltage filament lamp. This also applied when comparison was made with the 20- and 30-watt hot cathode lamps mentioned in the paper under discussion with their efficiencies of 18-19 lumens per watt, which he assumed were 100-hour figures also.

MR. B. F. W. BESEMER said he would like some verification of the statement by Mr. Tailby that he had obtained an efficiency of 15 lumens per watt and a life of 2,000 hours with incandescent filament lamps.

MR. TAILBY said it was a fact that a life of 2,000 hours was frequently being obtained from the 60-watt 25-volt lamp with an over-all efficiency of 15.0 lumens per watt.

MR. S. ANDERSON said he would like the authors' opinion regarding some of the variations of lamp characteristics at different supply frequencies as shown in Fig. 3. This raised a point which he had been turning over in his mind, viz., whether under these unusual supply conditions from the lamp point of view, it was preferable to run the lamp at its rated wattage or at its rated current, or at some intermediate value between the two. Obviously, the lamp could not be run at both the rated wattage and the rated current.

Another point on which he would like some information was the reason for the flattening-out of the curves in Fig. 3 towards the high-frequency end. Presumably some effect must come into operation at the higher frequencies which caused this; had any reason been found for the change in slope which seemed to happen at about 1,100 cycles?

He endorsed the suggestion by the authors that manufacturers and users should attempt to standardise on one, or at most, two, high frequencies for these transport applications of the fluorescent lamp. It seemed to him that the authors' choice of 400 cycles, or thereabouts, was the right one because he believed that much more groundwork had been done on that frequency than on any other, and the generating equipment seemed to be either available or more nearly available at that frequency than at any other. Further, from the data the authors had given, it seemed that by the time 400 cycles was reached, a very big proportion of the over-all benefit in various directions which could be obtained by going to higher frequencies had been achieved.

A point the authors had made some play with was the reduction in the

size and weight of the control gear to be obtained by going to high frequencies, and he had been rather surprised, in view of that, to see the dimensions of the control gear given by the authors. It seemed they had either designed it to have a very small temperature rise or, perhaps, they had used existing components which were rather larger than necessary. Could the authors elucidate that point? One very desirable feature was to dispose of the control gear behind the lamp it was associated with, although in many cases not much room was available behind the fitting for this purpose.

On the question of the difficulty of keeping lighting fittings clean, he said it would be interesting to hear whether London Transport had found any very great difficulties in maintaining the semi-enclosed type of fitting which had been so widely used on the Underground trains. Was there anything in the theory he had heard that by having an aperture in the lower part of the fitting, the dirt fell out by gravity. If that were the case, then it might be possible to achieve the degree of diffusion that was desirable with, at the same time, a fitting that was to some extent self-cleaning. A point not mentioned was that even a bare lamp would get dirty if there was dirt about. It might be easier to clean, being in the open, but the dirt problem was still there.

On the general point of fittings, he said that the flush fitting in the ceiling gave a dark and gloomy appearance. The scheme devised by the London Transport authorities, as shown in one slide by Mr. Graff-Baker, with 20-watt fluorescent lamps at the junction of the two ceiling curves, was a good one, because it provided sufficient offset to avoid the appearance of a dark ceiling.

He had been interested to hear the comparative cost of the gear for the higher frequency equipment as compared with that for the lower frequencies, and it seemed that very desirable economies in that direction had been achieved. He had been under the impression that although there was a saving in size with the higher frequency, the cost was so much bound up with the processes of manufacture and also, to some extent, with the higher cost of the materials involved, that there would not be very much saving in gear cost.

MR. R. R. HOLMES expressed satisfaction that the authors had given so much attention to brightness readings and hoped that others would follow this up, because brightness readings were a useful guide in arriving at comfort in interior lighting. In that connection he thought the scheme of the London Transport organisation of having 2-ft. tubes with alternate dark spaces was subject to certain criticisms. It was true the lamps continued the line of the structure, but the dark spaces definitely prevented the intermediate portion from receiving any direct illumination from the adjacent lamp, and the result was a rather severe alternation of bright and dark spaces.

MR. J. N. HULL, replying to some of the points raised in the discussion, said it was very encouraging to hear what Mr. Graff-Baker had said about the work being done by the London Transport authorities. In comparing the results obtained with fluorescent and filament lighting, he rather wondered whether they were comparing the same thing. It would be much more expensive to get, with tungsten filament lighting, the results that had been obtained with some of the experimental fluorescent lighting schemes. One difficulty was to compare the colour, which was an important advantage in favour of fluorescent lighting. There was one example in the paper where the comparison was made not in terms of £ s. d., but of power required, and it was shown that the illumination was up about five times, and only half the power was required, as compared with filament lighting.

MR. GRAFF-BAKER said the case he had in mind was the actual cost of

fitting the lamps in the car and maintaining them, excluding the converison equipment. That was a direct comparison between the fittings and lamp in each case on the new cars and on the old cars. The illumination level was very much the same in the two cases. It was quite certain that the renewal costs of the lamps with a reasonable expectation of life and the capital cost of the fittings and interest charges added together made fluorescent lighting a more expensive proposition than filament lighting.

Mr. Graff-Baker admitted that personally he got a certain satisfaction out of fluorescent lighting. He thought it was a better-looking job and one more easy to keep clean. The fitting that had been mentioned for filament lamps was designed so that the glass-ware removed without disturbing the lamp. The aim was to achieve easy cleaning, but, unfortunately, the dirt did not fall out of its own accord.

MR. HULL, continuing his reply, and commenting on the question of efficiency which had been mentioned by several speakers, said there were a number of figures in the paper and they were all between 18 and 20 lumens per watt of D.C., which was rather better than the 10 lumens per watt in the case of the equivalent size of filament lamp. It was, of course, possible to bulk the lighting points and use larger sources and so get a slightly higher efficiency, but it was not the same thing because by distributing the lighting points a more diffused and more evenly bright installation was obtainable. Therefore, he thought it fairer to compare similar sizes of lamps on the two systems, taking the over-all efficiency of the fluorescent installation. One of the reasons fittings were enclosed was to prevent damage to the lamp, although this might not arise under London Transport conditions.

MR. RUFF, taking up the reply, said that the point that his co-author Mr. Hull had been been making, viz., the desirability of comparing like with like, was extraordinarily difficult, indeed, it was asking for the impossible. However, everyone who had seen fluorescent lighting in transport vehicles—and he had seen it in France, America and this country—and he thought the best was in this country—were definitely satisfied that there was improved appearance, and it was this which Mr. Graff-Baker said he needed to sell his transport!

As regards the use of the 6-ft. cold cathode tubes on the New York Subway, mentioned by Dr. Strange, he said it would be possible to achieve the same or greater efficiency in vehicles with two 3-ft. hot cathode lamps operating at ordinary traction voltages, but the problem here was to avoid the use of long lamps and that made the hot cathode type essential. The gear system on the New York Subway was interesting, especially the method of getting switchless starting with D.C.

Two conflicting points had been put forward by Mr. Graff-Baker. One was that D.C. ought never to be used anyway—and he personally agreed for such applications as the London Transport system—and the other was that the use of A.C. involved the problem of costly transformation. However, the cost of the whole equipment, using D.C. as compared with A.C., was such that he thought it would be necessary to have some D.C. equipments. The initial cost of the latter was only 50 to 60 per cent. of the former, and that was the reason why the D.C. system was likely to be used on certain vehicles.

Finally, with regard to Mr. Anderson's question concerning cost, he said the curve was based on similar economy in manufacture. That meant there must be a minimum requirement in a given output and size to effect

such economy, so that if there was only a small requirement for the high-frequency choke, the reduction in cost would not be so much.

He promised to give a more detailed reply in writing.

Further written reply by the authors.

Some of the figures of available power in Table I are derived from the battery or machine capacity of existing designs of vehicles. Others, as Mr. Graff-Baker suggested, are fixed for reasons of economy, or, as in the case of a number of experimental installations, by a desire to compare fluorescent and tungsten installation with a common factor.

The disadvantage of the variable voltage and interruptions of the traction supply have been overcome technically, and the circuits in Fig. 9 will operate satisfactorily over the voltage range quoted by Mr. Graff-Baker. The illumination varies far less than when tungsten lamps are used on the same supply —approximately a quarter as much—and fluorescent lamps can therefore be considered a better proposition from this point of view.

The efficiency figures quoted by Mr. Tailby do not agree with our own experience. The average value over life of a 60-watt 25-volt 1,000-hour tungsten lamp is about 13 lumens per watt, as compared with about 24 lumens per watt D.C. which should be obtained from a 30-watt fluorescent lamp taking a similar power from the battery. The greater size allows higher efficiency, but this is indirect opposition to the transport engineers' desire for small units. One 30-watt fluorescent lamp would not provide very good compartment lighting, although, with its lower brightness, it would be much better than a bare 60-watt tungsten lamp.

All the efficiencies quoted in the paper refer to average values over the life of the lamp; about 15 per cent. should be substracted from the 100-hour values quoted by Dr. Strange to give an average overall efficiency of 19.5 lumens per watt for the 6-ft. cold cathode lamp. The life of the 20- and 15-watt fluorescent lamps used in the vehicle installations so far have, with suitable circuits, been only slightly less under stationary conditions and that is likely to be greater as more experience of the operating conditions is obtained.

In further reply to Mr. Anderson, the lamp characteristics in Fig. 3 have been plotted for constant wattage and the lamps are usually operated at rated wattage. The changes with frequency are thought to be mainly due to the reduced time for de-ionisation between current half-cycles, so that for each half-cycle the striking voltage and the lamp voltage will be less; the power factor is higher due to the consequent improved waveforms. The change in curvature near 1,100 cycles, no doubt, indicates the point where the de-ionisation becomes negligible and no further gain can be expected from this effect.

The high-frequency chokes have been designed for low loss and, incidentally, low-temperature rise as suggested by Mr. Anderson, to make the best use of the restricted power from batteries.

We are very interested to note Mr. Graff-Baker's work on built-in lighting systems with which we heartily agree, and we consider fluorescent lamps have a big advantage for such installations.

The Illuminating Engineering Society is not, as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—" Trans. Illum. Eng. Soc. (London)."

Additions to List of Members

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

CORPORATE MEMBERS:—

Allen, P. W. .....General Electric Co., Ltd., Magnet House, KINGSWAY, W.C.2.
Allport, A. J. .....14, Grosvenor Court, Grosvenor Road, BIRMINGHAM, 20.
Bailey, J. C. .....344, Welford Road, LEICESTER.
Barton, W. A. .....85, James Street, NEWCASTLE-ON-TYNE, 4.
Bonn, A. S. .....34, Polwarth Gardens, GLASGOW, W.2.
Brown, W. .....18, Melbury Road, Woodthorpe, NOTTS.
Clark, R. G. A. .....Deal and Walmer Gas Co., Cannot Street, DEAL.
Conradi, C. S. .....1, Flassburn Road, DURHAM.
Coombs, F. B. .....22, The Parade, Epsom, SURREY.
Cork, H. F. .....1, Middlefield, Ormsgill, BARROW-IN-FURNESS.
Gurney, T. H. .....6, Stourbridge Grove, CAMBRIDGE.
Halle, R. .....G. & W. (Lighting) Ltd., Glass Works, Church Lane, Dudley Port, Tipton, STAFFS.
Hamid Ali, S. .....56, Eglantine Avenue, Belfast, N. IRELAND.
Hirst, G. T. .....“Woodcroft,” Scatcherd Lane, Morley, Nr. LEEDS.
Howorth, J. R. .....213, Halifax Road, Rochdale, LANCS.
Ibbitt, A. I. .....37, Orlando Drive, Carlton, NOTTINGHAM.
Jenkins, D. R. .....3, Laburnum Terrace, Rhydyfelan, Pontypridd, GLAM.
King, M. H. .....33, Lafage Street, Bradford Moor, BRADFORD.
Lancelot, R. .....1, Rue Dulong, Paris, FRANCE.
Langford, S. .....44, Out Lane, Woolton, LIVERPOOL.
Love, R. H. .....23, Whitland Road, Fairfield, LIVERPOOL, 6.
MacDougall, D. .....34, Ravenshall Road, GLASGOW, S.1.
McIver, W. B. .....913, Dumbarton Road, GLASGOW, W.1.
McKnight, T. .....67, Warrenhouse Road, LIVERPOOL, 22.
Mare, A. J. .....18, Newhall Hill, BIRMINGHAM, 1.
Miller, W. J. .....67, Coniston Grove, Acklam, MIDDLESBROUGH.
Milner, E. .....36, Broughton Grove, Skipton, YORKS.
Parry, J. E. .....833, Ashton New Road, Clayton, MANCHESTER, 11.
Pickles, N. .....53, Cambridge Road, West Bridgford, NOTTINGHAM.
Powell, H. E. .....47, Braemar Road, O'ton, BIRMINGHAM, 27.
Radford, E. T. .....36, Shawmoss Road, GLASGOW, S.1.
Richardson, J. A. .....Dale Head, Nethercliffe Crescent, Guiseley, Nr. LEEDS.
Roskilly, C. S. E. .....101, Fernside Road, BALHAM, S.W.12.
Saunders, O. W. .....920, Warwick Road, Acocks Green, BIRMINGHAM, 27.
Scott, R. .....5, Nansen Street, Gorse Hill, Stretford, LANCS.
Smith, V. J. .....85, Riversdale Road, Romford, ESSEX.
Stephens, G. W. .....267, Highbridge Road, Wylde Green, Sutton Coldfield, WARWICKS.
Stewart, W. H. .....12, Burnbrae Road, Auchinloch, LENZIE.
Sunderland, T. D. .....20a, Lissenden Mansions, Lissenden Gardens, N.W.5.
Torrance, C. W. W. ...“Rosdyl,” Upper Road, Greenisland, Belfast, N. IRELAND.
Wordham, C. W. .....28, Mulgrave Road, Harrow, MIDDX.

STUDENT MEMBER:—

Wearne, S. H. .....99, Burnt Ash Road, LEE, S.E.12.

Sessional Meeting in London

A sessional meeting was held at the Lighting Service Bureau, 2, Savoy-hill, London, W.C.2, at 6 p.m., on Tuesday, January 11, 1949, when the chair was taken by the President (Mr. J. M. Waldram).

The minutes of the last meeting having been taken as read and approved, the President called upon Mr. H. R. Ruff to present the paper entitled "Transport Lighting with Fluorescent Lamps," by Mr. H. R. Ruff, Mr. J. N. Hull and Mr. R. V. Mills. The paper opened by analysing the problem of transport lighting in terms of requirements and limitations. The paper then went on to describe the characteristics of lamps and explained the choice between direct operation and a conversion of a more suitable electric supply. The paper also described new types of lighting equipment and concluded with a detailed account of the application of the systems developed to specific classes of vehicles.

After a vote of thanks, proposed by the President, had been carried, the discussion was opened by Mr. W. S. Graff-Baker, who was followed by Mr. E. W. Tailby, Dr. J. W. Strange, Mr. B. F. W. Besemer, Mr. S. Anderson and Mr. R. R. Holmes. The authors replied to the discussion and the meeting was closed.

Notice of Annual General Meeting

The annual general meeting of the Society will take place at the Royal Society of Arts, John Adam-street, London, W.C.2, at 6 p.m., on Tuesday, May 10, 1949, when the report of the Council and the accounts for the past year will be submitted and the usual resolution will be moved appointing auditors for the forthcoming year.

Following the annual general meeting an address will be given by Mons. L. Gaymard, chief engineer of the street lighting department of Electricité de France.

Fellowship

The following application for fellowship of the Society has been accepted:—

C. M. Frobisher.

Register of Lighting Engineers

It has been decided that under the existing regulations governing the inclusion of the names of corporate members of the Society on the Register of Lighting Engineers those making application under Regulation 6 (i.e. those who claim 10 years' practical experience in gas or electrical engineering or other approved vocation not less than half of which has been spent in illuminating engineering) need not provide the certificate required under Regulation 9 (ii).

This certificate is, however, required of those making normal applications.

It is pointed out that those corporate members wishing to make application under Regulation 6 must do so before February 1, 1950, after which date all applicants will be required to satisfy the educational requirements.

I.E.S. Regional Committees
Session 1948—1949

Centres:

BATH AND BRISTOL CENTRE (WESTERN AREA).

Chairman: L. Burdes. *Vice-Chairman:* W. C. Bowler. *Hon. Treasurer:* R. G. Capell. *Committee:* D. E. Beard, H. Foster, A. E. Hayward, E. A. Newburn, S. Poole, C. W. Rawlings, I. M. Robertson, H. Tabb, W. L. Tout, R. E. Tucker, H. Weston, J. West. *Hon. Secretary:* R. S. Hazell, c/o The General Electric Co. Ltd., Lawford Street, Old Market, Bristol 2.

BIRMINGHAM CENTRE (MIDLAND AREA).

Chairman: Dr. J. H. Nelson. *Vice-Chairman:* P. Hartill. *Hon. Treasurer:* J. Ashmore. *Press Liaison Officer:* F. E. Chapman. *Committee:* F. S. Ette, J. Forth, V. Heydon, Dr. A. J. Holland, S. D. Lay, R. A. Lovell, F. Penson, W. H. Randall, G. Satchwell. *Hon. Secretary:* W. J. P. Watson, 91, Brandwood Road, Kings Heath, Birmingham, 14. *Hon. Asst. Secretary:* W. E. Prendergast.

CARDIFF CENTRE (SOUTH WALES AREA).

Chairman: S. G. Turner. *Vice-Chairman:* J. S. Childs. *Committee:* J. Trevor Jones, J. S. Liversage, E. N. Lockyer, G. R. Lusty, H. W. Mabbett, J. H. Parker, H. W. Rees, R. E. Silvey, C. E. Springsguth, W. H. Stone, V. R. Treasure, V. G. Wackrow. *Hon. Secretary and Treasurer:* N. D. Houston, 54, St. Mary Street, Cardiff.

EDINBURGH CENTRE (SCOTTISH AREA).

Chairman: S. G. Batt. *Vice-Chairman:* H. D. Purvis. *Hon. Treasurer:* H. Stanway. *Committee:* L. R. Brown, H. Buckley, J. S. Galbreath, I. W. Hunter, C. Norman Kemp, W. Mackenzie, C. K. Ross. *Hon. Secretary:* G. E. L. Comrie, 4, Silverknowes Terrace, Edinburgh, 4.

GLASGOW CENTRE (SCOTTISH AREA).

Chairman: D. Ross, *Vice-Chairman:* A. MacGregor. *Hon. Treasurer:* J. Welsh. *Committee:* T. Dunnett, A. Kelso, C. J. King, J. Langlands, J. M. Henshaw, E. J. Stewart, A. B. Wright. *Hon. Secretary:* A. M. Rankin, 53, Pitt Street, Glasgow, C.2.

GLOUCESTER AND CHELTENHAM CENTRE (WESTERN AREA).

Chairman: J. Davoile. *Vice-Chairman:* W. Holtam. *Hon. Treasurer:* H. V. Sayce. *Committee:* B. J. Dyer, J. F. Edgell, G. R. Hadley, W. Hill, B. C. Mitchell, L. C. Mitchell, I. R. Morgan, W. T. Turner, H. V. Williams. *Hon. Secretary:* I. S. Freemantle, 33, Church Road, Longlevens, Gloucester.

LEEDS CENTRE (NORTH MIDLAND AREA).

Chairman: J. D. Green. *Vice-Chairman:* T. C. Holdsworth. *Hon. Treasurer:* A. Wilde. *Committee:* J. R. Bardsley, E. Bastow, E. A. Fowler, R. D. Green, H. W. Harris, P. C. Harrison, J. W. Howell, A. G. Smith, E. Smith, S. K. Spencer, E. C. Walton, J. H. Weaver. *Hon. Secretary:* A. Wilcock, 49, Bazinghall Street, Leeds, 1. *Asst. Hon. Secretary:* E. Bastow.

LEICESTER CENTRE (MIDLAND AREA).

Chairman: F. Jamieson. *Vice-Chairman:* R. K. L. Davies. *Hon. Treasurer:* F. J. Stanyon. *Committee:* F. A. Bell, E. C. Came, P. H. H. Jantzen, H. H. S. Mansfield, R. H. Phillips, G. C. B. Webb, T. Wilkie. *Hon. Secretary:* W. N. Coulson, 5, Campbell Street, Leicester.

LIVERPOOL CENTRE (NORTH WESTERN AREA).

Chairman: O. C. Waygood. *Vice-Chairman:* C. C. Smith. *Hon. Treasurer:* W. T. Trace. *Committee:* R. W. J. Benyon, N. Blackman, P. Bregazzi, F. G. Copland, E. M. Duke, L. G. Harris, Tom Jones, K. E. Pickard, F. W. White, A. Winstanley, T. D. Woods. *Hon. Secretary:* K. R. Mackley, Inner Temple, 24, Dale Street, Liverpool. *Asst. Hon. Secretary:* F. J. Burns.

REGIONAL COMMITTEES

MANCHESTER CENTRE (NORTH WESTERN AREA).

Chairman: H. Atherton. *Vice-Chairman* F. J. R. Makin. *Hon. Treasurer:* H. Etchells. *Committee:* W. C. G. Bailey, F. S. Boucher, E. J. Bull, W. G. Chilvers, Mrs. I. H. Hardwich, J. Martin, T. Metcalfe, J. H. Morrison, T. L. Robinson, J. Walsh, H. Wilcock. *Hon. Secretary:* W. E. Ballard, "Fair Rigg," Fairview Road, Timperley, Cheshire. *Asst. Hon. Secretary:* Alan H. Owen.

NEWCASTLE CENTRE (NORTH EASTERN AREA).

Chairman: H. L. James. *Vice-Chairman:* A. J. Ogle. *Hon. Treasurer:* J. Stewart. *Committee:* L. Charlton, W. H. Dodgson, C. Fielding, R. W. Gregory, G. R. Hanson, A. S. Lowery, J. S. McCulloch, W. Sancto, P. S. J. Underwood. *Hon. Secretary:* D. L. Tabraham, 25, The Drive, Gosforth, Newcastle-on-Tyne.

NOTTINGHAM CENTRE (MIDLAND AREA).

Chairman: W. K. Martin. *Vice-Chairman:* R. H. Ellis. *Hon. Treasurer:* P. L. Ross. *Committee:* J. C. Charity, G. Honnorarty, A. G. Kidd, A. R. Law, R. G. Mountford, E. G. Phillips, R. J. Pickford, N. C. Slater, G. C. Small, F. Walker. *Hon. Secretary:* A. Hacking, 32, St. Leonard's Drive, Wollaton, Nottingham.

SHEFFIELD CENTRE (NORTH MIDLAND AREA).

Chairman: B. Bingham. *Vice-Chairman:* H. B. Leighton. *Hon. Treasurer:* C. Hadfield. *Committee:* J. G. Charlton, H. Dick, D. H. Fox. B. B. Hayter, H. Lewis, G. E. Rodger, W. G. Symons, E. G. R. Taylor, W. G. Thompson, G. L. Tomlinson, H. Wheeler, A. Wylie. *Hon. Secretary:* M. G. Lockwood, 12, James Andrew Crescent, Greenhill, Sheffield 8.

Groups:

BRADFORD GROUP (NORTH MIDLAND AREA).

Chairman: W. B. Jamieson. *Committee:* T. N. Hird, H. Moss, W. H. Naylor, A. S. Redvers Pratt, N. Rhodes, L. Robinson, J. H. Rogerson, F. S. Warburton. *Joint Hon. Secretaries:* A. J. Hutchison, 45/53, Sunbridge Road, Bradford, W. H. Naylor, 40, Godwin Street, Bradford.

EXETER GROUP (WESTERN AREA).

Chairman: F. D. Newcombe. *Committee:* D. R. Beckett, H. H. Brown, W. E. Browning, H. T. Corrigan, C. Lye, L. D. H. Rowe, F. W. Sansom. *Hon. Secretary:* L. W. Cornish, 46, North Street, Exeter.

HUDDERSFIELD GROUP (NORTH MIDLAND AREA).

Chairman: H. L. Walker. *Vice-Chairman:* M. E. Broadbent. *Committee:* F. Eastwood, R. Hardy, G. Ripley, W. Robinson, N. Schofield, E. C. J. Swabey, J. T. Thornton, H. Walton. *Hon. Secretary:* E. Wood, 11, Long Grove Avenue, Dalton, Huddersfield,

STOKE ON TRENT GROUP (MIDLAND AREA).

Chairman: T. Lockett. *Vice-Chairman:* E. N. Farnsworth. *Committee:* F. Claxton, W. A. Fisher, A. Gould, J. R. Piggott. *Hon. Secretary:* J. P. Oliver, 31, Kingsway, Stoke-on-Trent.

SUSSEX GROUP.

Chairman: E. Stroud. *Committee:* H. Barlow, R. Davidson, C. F. Green, V. B. J. Green, A. F. Harvey, M. W. Hime, R. T. Maundrell, J. R. Yeates. *Hon. Secretary:* A. P. Cole, 35, Wellington Road, Brighton, 7.

TEES-SIDE GROUP (NORTH EASTERN AREA).

Chairman: N. Hunter. *Vice-Chairman:* D. B. Hogg. *Hon. Treasurer:* G. H. J. Sansom, *Committee:* K. Graham, J. Kirby, R. K. Leslie, R. W. Oxley, M. A. Raisbeck, S. O. Shircore. *Hon. Secretary:* J. M. Sandford, Magnet House, Corporation Road, Middlesbrough.

Printed by ARGUS PRESS, LTD., Temple Avenue and Tudor Street, London, E.C.4., England